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SPACE TELESCOPE COST, SCHEDULE, AND PERFORMANCE REVIEW 1984

REPORT

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LETTER OF SUBMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC, October 1, 1984.

Hon. DON FUQUA,
Chairman, Committee on Science and Technology,
U.S. House of Representatives.

DEAR MR. CHAIRMAN: The Subcommittee on Space Science and Applications held two days of hearings in May 1984 to review the cost, schedule, and performance of the Hubble Space Telescope program. It is important to focus on these issues because the Space Telescope is a large step towards the future when we will be utilizing and maintaining science facilities in space. This program will significantly affect: (1) the requirements for the future space transportation system and our space infrastructure; (2) the philosophy underlying our approach to permanent operation in space; and (3) NASA's future relationship with the science community.

This report summarizes the testimony, which is published as a separate document, and outlines key issues raised during the hearings.

These hearings were organized and the accompanying report prepared with the assistance of Dr. William S. Smith, a Department of Commerce Science and Technology Fellow.

Sincerely,

HAROLD L. VOLKMER,
Chairman, Subcommittee on Space Science and Applications.

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I. INTRODUCTION

The Hubble Space Telescope is one of the largest and most challenging science projects ever undertaken by NASA. When the Space Telescope project was initiated in 1978, the total runout cost was estimated at $435 million. During recent authorization hearings, the total cost was estimated to be $1.175 billion. Taking account of inflation, this represents over $500 million in cost overruns. The launch date has slipped from 1983 to the latter part of 1986, which will miss a major objective of viewing Halley's Comet.

Past major problems which have led to cost increases and schedule delays include development of fine guidance sensors which will enable the telescope to orient itself with respect to faint stars, unanticipated flaws in materials and design associated with the orbital replacement unit latches, and the need to fabricate the mirrors in a clean environment. Although other technical challenges may yet arise, the resolution of most of these problems appears to be in sight. It is now appropriate to look beyond the developmental phase and examine the cost and scenario of maintaining a permanent scientific facility in space.

On May 22 and 24, 1984, the Subcommittee held oversight hearings to review the cost, schedule, and performance of the Space Telescope program. These hearings coincided with a particularly crucial time in the Space Telescope program. The manufacturing phase was drawing to a close and the assembly and integration phase was scheduled to begin in November 1984. Any problems found at this time could severely impact the remaining schedule and diminish the science return. It was also a crucial time because the true scope of the requirements for maintenance and refurbishment was just beginning to be considered. Finally, after two years of start-up operation, the role of the Space Telescope Science Institute was taking final form, and the Subcommittee wanted to compare its present status with that originally envisioned.

The hearings examined these issues. This report summarizes these issues and the Subcommittee's findings based on the testimony received during the hearings.

II. BACKGROUND

Since the earliest days of ground-based astronomy, observers have been hampered by several fundamental limitations. First, the resolution, or the detail discernible by the telescope, is strongly affected by the ability of the lens or reflecting mirror to bend the light rays to form a well defined focal point. As the diameter of the telescope increases, this focal point becomes better defined and undesirable light bending effects, called diffraction, become of less importance.

Another fundamental limitation relates to the effects of the atmosphere. The characteristic twinkling of stars is actually a continuous change in apparent position as the light is refracted through the turbulent atmosphere in which temperature inhomogeneities exist. For this reason, many astronomical observatories have been located at high altitudes to minimize the amount of the atmosphere through which the light would have to travel. In addition, the absorption of ultraviolet and infrared radiation by atmospheric gases severely limits the capability to characterize stellar objects by means of ground observations.

As early as 1962, NASA and the scientific community recognized the benefits of placing an optical instrument above the Earth's atmosphere. At that time, the National Academy of Sciences pointed out that without the limitations imposed by the light scattering and absorption due to atmospheric gases and particles, far greater resolution could be obtained and much fainter objects could be observed. If the current design for the Hubble Space Telescope is successfully implemented, it will be able to observe objects seven times farther away and fifty times fainter than any other ground-based telescope. The observable time or distance accessible to man will be increased from 2 to 14 billion lightyears. Light in the near infrared, visible, and ultraviolet will be observable and spectral analysis will lend great insight into the evolution of stellar objects.

The data from the observatory will lead to a profound understanding of man's place in the universe. It may enable scientists to distinguish planetary systems associated with other stars. The Telescope has been designed to observe certain objects, known as Cepheid variables, which will allow a precise calibration of the distance scale and the rate of expansion of the universe. This rate of expansion is known as Hubble's Law, named after Edwin Hubble who first deduced this phenomenon from observing the redshift of remote galaxies. Not only is this crucial to understanding the nature of all other extragalactic objects, but it will also provide insight into such questions as the ultimate fate of our expanding universe.

NASA's Space Telescope project represents a substantial departure from other satellite astronomical missions in several ways. First, to achieve its scientific objectives, the Space Telescope requires an extremely large aperture of 2.4 meters, some 3 times larger in diameter than any previous satellite telescope. In addition to its greater resolving power, this allows greater light collection efficiency and shorter observation times for faint objects. Second, the observatory is intended to be permanent and thus compatible with other elements of the Space Transportation System inlcuding the Space Shuttle and Space Station. The Observatory will be capable of being serviced by astronaut specialists on-orbit. Items believed to be likely to fail have been designed as orbital replacement units.

Finally, in addition to its technical innovations, the Space Telescope program will employ a somewhat novel organizational approach to science operations and data management. This approach was formulated by a special study carried out by the National Academy of Sciences. This study is popularly referred to as the Hornig Report, named after the Chairman of the committee which conducted the review. Following the recommendations of the Hornig Committee, NASA has contracted with AURA, a university consortium which operates several ground-based national optical observatories to establish the Space Telescope Science Institute adjacent to Johns Hopkins University. The Institute, managed and operated by scientists, is supported by a contract between NASA and AURA, but remains essentially independent.

Following extensive feasibility studies, NASA began the procurement and construction phase for the Telescope in FY 1978 with the issuance of contracts for the Optical Telescope Assembly, the Support Systems Module and the Scientific Instruments. Original plans called for the Telescope to be launched and fully operational by 1983. This capability would have been of enormous value for the observation of Halley's Comet, which would approach Earth in November 1985.

The nature of the scientific objectives of the Space Telescope program together with the engineering requirements for such a complex unmanned piece of equipment have presented technical challenges which have greatly exceeded NASA's original expectations. The Space Telescope is now considered one of the most challenging projects ever undertaken by NASA.

In accommodating the unanticipated degree of these challenges, the project has suffered major schedule slippage and a cost growth of over $500 million. Several reprogramming actions have been necessary which have impacted the progress and health of other programs.

The inability to fully anticipate, plan, and budget for the problems encountered has been attributed by some observers to management deficiencies both with contractor organizations and within NASA. During the course of the development, NASA has taken a number of initiatives to exercise greater oversight of contractor efforts and to bring to the project greater management attention.

Prior to this hearing, the Subcommittee had held two other major hearings related to the Space Telescope. In May 1982, an oversight hearing was held which reviewed the overall program and examined the role of the newly established Science Institute in Baltimore. Shortly after the 1982 hearings, NASA disclosed the true extent of budgetary and technical problems being encountered. Hearings were held in June 1983 to focus on these technical problems and why they were not identified earlier.

Due to the magnitude of these developmental problems, the Subcommittee has not examined in detail the cost or scenario for the post-launch era. Therefore, the May 1984 hearings were designed to address several key questions:

- What are the remaining developmental problems and what is the outlook for maintaining the scientific goals and specifications during the final assembly and verification phase?

- Have the goals of the Hornig report been met and will the Science Institute fulfill the role envisioned in making the observatory as responsive as possible to its users?

- What will be involved in maintaining the performance of the observatory and the continuity in science return?

Witnesses were invited to express their views on these issues and to characterize for the Subcommittee the present status of the Space Telescope program and its future plans. Witnesses were invited from both the science community and NASA organizations having roles in the program.

III. SUMMARY OF WITNESS TESTIMONY

This section summarizes the testimony of witnesses in order of their appearance.

Dr. Lyman Spitzer, Princeton University Observatory

Dr. Spitzer chairs the Space Telescope Institute Council which was established to exercise administrative oversight over the Science Institute. The Council independently provides advice to the Board of Directors of the Association of Universities for Research in Astronomy, which manages the Science Institute as well as several other observatories.

Dr. Spitzer was asked by the Subcommittee to discuss the status of the development of the Institute and to assess how the evolution of the Institute has fulfilled the concept envisioned in the National Academy of Sciences Hornig Report. Dr. Spitzer's testimony gave a generally positive view of the Institute's progress and its accomplishment of the objectives of the Hornig report.

Dr. George Field, Center for Astrophysics

Dr. Field testified in his capacity as Deputy Chairman of the Space Telescope Advisory Committee. This Committee was established to advise the Director of the Science Institute on the potential of the Space Telescope to meet the needs of the community, the prioritization of science objectives, the optimum scientific use of the observatory, and the relationship between the Institute and the science community.

Dr. Field stressed that the science community views the Space Telescope as an extremely valuable resource and the demand for utilization will very likely exceed the available observing time. He described the system of peer review by which proposals will be categorized and considered. He also outlined the approach that will be taken towards implementing "key" projects which are of outstanding scientific merit but require a substantial amount of observing time.

Dr. Robert C. Bless, University of Wisconsin

Dr. Bless is Chairman of the Space Telescope Observatory Assessment Team which was established to provide an independent assessment of the Space Telescope development program in order to ensure that all science objectives will be met. Dr. Bless also commented as a principal investigator and user of the Space Telescope, on the overall responsiveness of the Observatory program to user needs.

Dr. Bless indicated that most of the developmental problems identified in early 1983 have been resolved and that significant progress has been made. He cautioned, however, that the assembly and verification phase is of concern and that detailed planning for this has not been adequate.

Dr. Burton I. Edelson, accompanied by Mr. Samuel Keller, NASA Headquarters

Dr. Edelson, Associate Administrator of the Office of Space Science and Applications, was asked to review the overall cost and schedule of the Space Telescope developmental program. He was also requested to assess the impact of post-launch costs on NASA's Space Science and Applications program.

Mr. Keller described the current cost and schedule situation and reviewed the progress towards resolving previously identified technical problems. He also notified the Committee that, due to the high costs and risks associated with a ground return for refurbishment, NASA currently is considering on-orbit refurbishment utilizing the Space Station. Finally, Mr. Keller assured the Committee that the development phase could be completed within the projected runout cost of $1.175 billion and that the 1986 launch date commitment could be met.

Dr. William R. Lucas, Marshall Space Flight Center

Dr. Lucas was requested to testify on the developmental problems and future technical and schedule risks remaining in the Space Telescope program, particularly during the systems integration phase. He was also asked to assess the goals and requirements of the post-launch maintenance and refurbishment program.

Dr. Lucas testified that much progress has been made on the fine guidance sensors, orbital replacement unit latches and mirror contamination. He also described schedule recovery plans for those portions of the program currently behind schedule and the elements of probable risk during the assembly and verification phase.

Finally, Dr. Lucas characterized the maintenance and refurbishment program as being under review.

Dr. Noel Hinners, Goddard Space Flight Center

Dr. Hinners described the role of the Goddard Space Flight Center in the management of the Observatory's science instrument development programs and its ground operations system.

Notwithstanding several remaining developmental problems, Dr. Hinners indicated that the science instruments will be completed in time for their integration into the rest of the spacecraft assembly. He also testified that an adequate ground system to support both engineering and science requirements will be available for the 1986 launch.

Dr. Hinners also described the evolving role of the Science Institute and its relationship to NASA. He characterized the overall budget constraints and the impacts on the size and scope of the Institute.

Dr. Sandra M. Faber, University of California, Lick Observatory

Dr. Faber described the role and activities of the Space Telescope Institute Visiting Committee, which she chairs. She characterized the Visiting Committee's view that all of the tasks that have evolved for the Institute are appropriate and necessary to the operation of the Observatory. She testified that, although the costs of the Institute should not be allowed to grow unduly, the present size is appropriate to the complexity of operations expected for the Observatory.

Dr. Faber also described the Visiting Committee's particular interest in developing a data archive system which will be fully responsive to the anticipated large number of users. Such an archive system, she testified, will provide access to the observatory for a much broader community of astronomers than would be possible through direct allocation of observing time.

IV. MAJOR ISSUES

Several major issues were discussed during the course of the hearings which are related to the remaining developmental problems, the post-launch cost and scenario for logistics and operations, and the responsiveness of the observatory infrastructure to its users. These issues are outlined using witness testimony, dialogue between witnesses and Members, and written material supplied for the record of the hearing.

A. Remaining Developmental Challenges

In commenting on the overall progress towards resolving major problems identified in the past, Dr. Bless stated: "The outlook for Space Telescope is much brighter than it was 18 months ago. Many serious problems have been resolved. The program is rapidly moving ahead."

A similar view was reflected in the testimony of the NASA witnesses. Mr. Keller testified:

> " . . . we are proceeding in accordance with our rebaselined plan toward a launch in the second half of 1986. At the present time, we believe we can meet that date and not exceed the projected runout cost estimate of $1.175 billion.
>
> . . . the space telescope is an incredibly complex program, which has created demanding state-of-the-art requirements in many technical areas. ...our present plan provides an appropriate mix of schedule realism, while demanding superior performance by both the government and the contractor organizations."

Dr. Lucas stated:

> " . . . substantial progress has been made since my report last June. The project is progressing well and within the estimated run-out costs.
>
> The optical telescope assembly is essentially on schedule, and the outlook is good for delivery to Lockheed as planned, in November of this year. While Lockheed has experienced some problems on the support systems module, positive steps have been taken to enhance the capacity to meet project schedules."

Notwithstanding the good progress that has been made thusfar, several issues were identified which may impact the remaining developmental phase. Specifically, the assembly and verification phase which begins in November 1984 was characterized by Dr. Bless as follows:

> "It is this phase of the program which STOPAT[1] finds more problematic than any other. The test facilities and the mechanical and electrical support equipment seem to be in good shape. The test systems software, which actually runs a test, however, is not scheduled to be ready until this July. Furthermore, it does not seem to us that the detailed planning for the various tests and their implementation in software is as far along as it should be."

Chairman Volkmer questioned Dr. Bless on whether the assembly and verification phase contained an adequate level of slack time (85 days) to accommodate technical problems that may arise. Dr. Bless responded:

> "As a matter of fact, I don't believe that this whole test program has been looked at very carefully from the point of view of how much time would be necessary and whether the re-test factors were reasonable or not. It's also not clear how productive that would be. It's a very difficult thing to set up because you're doing something that's rather new, rather different, so it's hard to make the estimates.
>
> Our concerns on STOPAT are that the preparations do not appear to us to be adequate. [We] soon will be beginning this whole 16-month, 18-month program, and this is what concerns us a great deal. I guess I would say that if our preparations had been adequate we would be happier with the 85 days. As it is now, the suspicion is that perhaps the 85 days will not be sufficient."

Dr. Lucas' testimony set forth the NASA view on the assembly and verification phase as follows:

> ". . . this is a very significant and complex phase of the space telescope project. And the contractors' efforts are being monitored closely to minimize schedule risks...
>
> ... the schedule risks resulting from potential difficulties in completing electronic assemblies, the test software and electrical ground support equipment, and contamination control, represent the greatest concerns with the Lockheed effort."

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[1]Space Telescope Observatory Performance Assessment Team.

It was implicit throughout the NASA testimony that the remaining schedule and procedural plans represent a close balance between science and engineering considerations and costs attendant to schedule delay. This was best illustrated in discussion pertaining to whether or not the primary mirror should be cleaned of particulates which would degrade its optical qualities. In questioning, Chairman Volkmer asked Dr. Lucas, "The other thing that concerned me during your testimony, you used the word 'if', I believe, when ... you were discussing the cleaning of the primary mirror. Is it 'if' or 'when'?" Dr. Lucas replied:

> "It is indeed 'if', because we have a decision meeting on that early in June to decide whether to clean or not to clean. We have developed a system to clean; we started that last year.
>
> That system has been developed, thoroughly worked out, prepared for and then a decision will be made early in June if we actually proceed with the cleaning."[2]

He further characterized the decision as follows:

> "Is the contamination now sufficient, added to a reasonable anticipation of additional accumulation of contamination, to warrant the time and the expense to make the cleaning?"

In reflecting a science view on this issue, Dr. Bless testified:

> "Now since the present level of contamination is just barely acceptable, and there is every expectation that even under the best of circumstances it will increase, cleaning the primary mirror is a good thing to do."

The central question of concern to the Subcommittee was the possibility that the scientific potential of the Observatory might be sacrificed to some degree by programmatic decisions to adhere to the planned schedule even if unresolvable difficulties might arise. Chairman Volkmer posed a hypothetical situation in which a science instrument was not available, and asked whether or not NASA would delay the launch. Mr. Keller replied:

> "If the delay became great enough, I think the time would come when we would go ahead and launch and then put that instrument on-orbit during a revisit trip, but I am not sure I can give you a real hard hypothetical answer that says that six weeks I do that, and then four weeks I wouldn't."

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[2](Following the hearing, NASA announced its decision to clean the mirror. NASA characterized the result of that operation as highly successful.)

Thus, although NASA has not developed any contingency plans for specific science tradeoff decisions, the possibility exists that some diminished science capability would be acceptable to NASA in lieu of a delayed launch date. Mr. Keller characterized such a delay as potentially costing $10 to $12 million per month. Although a diminished science capability would be inconsistent with the very purpose of the program, practical considerations dictate that, at some point, the cost of delay would be unacceptable. NASA could perhaps prevent criticism by developing decision procedures involving the scientific community in anticipation of situations that could arise at launch time.

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B. Scope of Responsibilities of the Science Institute

A major focus of the hearing was to reexamine the relationship between the observatory and its users which is realized through the Space Telescope Science Institute. The Subcommittee revisited the original concept for the Science Institute as envisioned in the Hornig report. Major questions pertained to the scope of responsibilities of the Science Institute, the views of the science community toward the Institute, and the applicability of the Institute concept to other major observatories such as Advanced X-Ray Astrophysical Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF).

With respect to the scope of responsibilities for the Institute, Dr. Spitzer summarized the findings of the Space Telescope Institute Council as follows:

> "A good framework for review is the set of plans originally prepared by the National Academy committee under the chairmanship of Dr. Donald Hornig. This Committee recommended four basic functions for the Science Institute ...
>
> One, planning the scientific program for the Space Telescope; two, participating with the NASA project in tradeoff decisions and design modifications during ST development and refurbishment; three, preparing to monitor ST performance and to process all relevant scientific and engineering data; four, promoting productive participation by visiting scientists and first-rate research by the Institute's staff.
>
> While the second function has been only partially activated, partly because the Science Institute was created late in the ST program, the other three functions which represent more the scientific aspects of the ST program now provide the core program of the Institute, and would seem to correspond very closely indeed with the recommendations of the Hornig Committee."

Reflecting a similar view, Dr. Faber testified:

> "A major factor in establishing the Science Institute and outlining its function and composition was the Hornig report prepared some years ago by the National Academy of Sciences. The Visiting Committee spent some of its time in considering whether the Science Institute, in practice, is developing along the lines that are consistent with the precepts of this report. Our Committee concludes that it is, and that the Institute is so far generally on the right track. More specifically, we believe that it has proved extremely useful so far in the Space Telescope project to have a group of scientists in place well before the telescope is launched to advise NASA on

> scientific matters, review the interactions between various phases of the project, and plan for the data handling and analysis after launch. The project is an extremely complex one, and it is important to have a group of astronomers with a global view, such as the Institute has been able to take.
>
> In total, then, we feel that the present activities of the Science Institute are very much in the spirit of the Hornig report and are consistent with maximizing the scientific return from the ST mission."

An exception to this general assessment by these two witnesses pertains to the role of the Science Institute in participating in decisions relative to maintenance and refurbishment from a science standpoint. The following dialogue on this point took place between Chairman Volkmer and Dr. Faber:

Mr. Volkmer: The original Hornig report suggested that the Institute have a role in defining maintenance and refurbishment policy from a science standpoint. In your opinion, has any of this occurred . . .?

Ms. Faber: Not that I know of.

Mr. Volkmer: Alright. Should it occur? Should there be at least some input --

Ms. Faber: Of course.

Mr. Volkmer: -- in the policy decisions?

Ms. Faber: Yes.

Another issue which was of general concern to all of the witnesses was the growth of the Institute staff beyond that envisioned by the Hornig report. Dr. Spitzer explained this growth in the following way:

> "The staff size envisaged by the Hornig Committee was about 100 people. This figure was very provisional; for example, it made no allowance for round-the-clock operation of certain key facilities. Hence, it is not surprising that the actual number of people now known to be required for these necessary activities is about twice the early estimate, though in fact I should point out that it is only 20 percent greater, the number of people now required is 20 percent greater than the estimate in the original ... proposal for the Space Telescope Science Institute."

Dr. Spitzer further discussed specific areas where increases in staff have occurred. He said:

> "One example of the increased manpower requirements is provided by the Science Operation Ground Systems -- usually known as SOGS -- for which the detailed software program is being written by a commercial firm, TRW, directly under NASA control. At the start of this TRW effort it was estimated that 85 persons, many working around the clock, would be needed to operate the system which programs the Space Telescope in detail and carries out routine processing of the scientific data. At the moment, it appears that the actual number required for operating SOGS is greater by 30 persons, more nearly 115 rather than 85. Similar manpower increases have occurred in other areas."

Dr. Faber's testimony amplified this view in the following way:

> " . . . the Visiting Committee also recognizes that the present size of the Institute is significantly larger than originally planned. To put this growth in perspective, one notes that the entire ST project as a whole has turned out to be somewhat larger and more complex than originally envisioned. Some of these extra tasks in the prelaunch phase have devolved upon the Institute. The post-launch operations have likewise turned out to be more complex than anticipated. For these reasons, the original Hornig staffing levels probably should not be taken too literally.
>
> At the same time, we also recognize that costs of the Institute should not be allowed to grow unduly as the total budget for space astronomy in the U.S. is limited and room must be found in it to pursue other deserving projects beyond Space Telescope."

Chairman Volkmer emphasized that the entire discussion on the level of staffing at the Institute must take place in the context of a limited budget. He expressed the concern that the most likely scenario for the future NASA budget is one which is stable with a very slight increase and most of that increase going to the Space Station. Thus, unplanned increases in one part of the Astronomy program must necessarily work to the detriment of other parts. This would jeopardize the health of other programs such as AXAF and SIRTF planned to begin development in the mid 1980s.

C. Prioritizing Science Objectives of the Space Telescope

Inasmuch as the Space Telescope will be the centerpiece for astronomy in the coming decades, the Subcommittee was particularly interested in the plans for selecting specific proposals and prioritizing observing programs that will best benefit science. One of the major objectives in establishing the Science Institute was to create a framework wherein the scientists themselves would define and manage the science program.

In his opening statement, Dr. Field described the enormous complexity of the task of reviewing the number of proposals expected. He said:

> "Now as the Institute tries to design a system for giving an adequate peer review to the many hundreds, if not thousands, of proposals to be received covering a wide range of astronomical specialties, it is clear that there must be a very detailed and complex plan to deal with this system every few months. In particular, STSI[3] plans to establish what they call a Time Allocation Committee, or TAC, which is broadly representative of the specialties within astronomy.
>
> . . . Because it is especially difficult and important to fairly compare projects within quite different subdisciplines, TAC as a whole, including the chairs of the subdiscipline panels and additional members-at-large, will review the rankings of each panel and will form a master list of all proposed projects prioritized according to the preestablished criteria. This list will then be recommended by TAC to the director of STSI for implementation."

Dr. Field also discussed the allocation of time to key projects of great scientific value. This has no precedent in ground based observatories but is deemed to be appropriate due to the unique scientific capabilities of the Space Telescope. He stated:

> ". . . it has not been traditional in optical astronomy to separate out such key projects for special treatment. STAC[4], however, believes that it is necessary to do so with the Space Telescope because the ST is a uniquely powerful instrument, capable of a definitive attack on certain difficult problems which have broad impact in astronomy. STAC believes that the opportunity to attack such problems should not be lost and that key projects

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[3]Space Telescope Science Institute.

[4]Space Telescope Advisory Committee.

should be carried out even if they do require a substantial fraction of the observing time."

Dr. Field emphasized that the key project concept and the selection of key projects will be a unique and valuable exercise for the scientific community and will generate much discussion.

Mr. Chandler (R-Washington) expressed concern that the administrative structure for developing key projects may result in some subjectivity in the selection process. The following dialogue took place:

Mr. Chandler: I am concerned . . . that we make good decisions on the use of this telescope, especially given the resources being devoted to it, and ...that we not... satisfy people who might otherwise pursue their -- as you put it -- key projects, simply because they are part of a working group. I would assure the Congress that we're not simply giving everybody their little slice to keep them quiet, but that we really are going to come up with key projects that can best be served by the Space Telescope and that some people may well go away mad, and come here and complain. Well, so be it, as far as I am concerned, but I would like to hear an assurance that you are going to use the best judgment and the best use of the time . . .

Dr. Field: ... I believe that the philosophy, as I explained it in my presentation, is precisely that the proposals which are successful should be those which are of highest scientific merit, from whatever subdiscipline of astronomy they may come. The reason that we are contemplating a division of some of the activities of this review committee -- the Telescope allocation committee or the time allocation committee -- into various subdisciplines is not a political one but a scientific one, stemming from the fact that it has already been verified that there will be large numbers of proposals in each of these subdisciplines. Therefore, there have to be experts to evaluate them. That would be the first step of the process.

Dr. Field further discussed the difficulties in prioritizing objectives from different astronomical disciplines. He characterized the difficult problems which may confront the Time Allocation Committee as follows:

". . . there will be a tendency, in all honesty, for each subdiscipline to claim a certain fraction of the observing time. It will take great effort and determination to not yield to that pressure. That is the current thinking of our committee, that the time allocation committee should not yield to that pressure; that it should interweave the proposals from the various disciplines on the

> basis of overall scientific merit, judged as best as can be done by the Chairs of these subdiscipline panels plus some outside members."

The influence of conflicting pressures on the proposal selection process was also discussed by Dr. Faber. She testified:

> "One of the major questions being asked is just how many proposals per telescope time the Institute will receive and how many of these proposals should be accepted. A major concern here is the anticipated high oversubscription . . . of time [which] is expected to be very large, and it is understandably tempting under such circumstances to divide the time into many small pieces to satisfy as many users as possible.
>
> However, it is the prevailing opinion in the astronomical community that an effective scientific program cannot be mounted with such a strategy since major programs needing large allotments of time would be precluded. In view of these conflicting pressures, it is clear that fair and wise allocation of telescope time will be a major responsibility of the Science Institute and must be planned for carefully in advance."

Drs. Faber and Field also discussed the results of a questionnaire distributed by the Science Institute which indicated that up to 1,500 proposals per year could be expected after launch. Dr. Faber compared this to the availability of observing time in the following way:

> "In a parallel planning study a distinguished advisory committee concluded that an optimum scientific program for the telescope could accommodate approximately 300 proposals in total. This large oversubscription factor of three or five to one, depending on exactly how one calculates it, emphasizes the need for proper screening procedures . . .
>
> I would also like to stress the following point. The high percentage of responses to the Institute questionnaire and the large number of prospective users of Space Telescope that it revealed demonstrates more clearly than any previous survey the extraordinary enthusiasm for the Space Telescope project that exists among astronomers and the widespread consensus in the community that the Space Telescope will revolutionize ultraviolet and optical astronomy as we now know it."

Implicit in the testimony of the witnesses was the fact that the science operations and data management for the Space Telescope will be a novel and innovative experiment. A key element in this approach will be the extent to which the science community will be called upon to make decisions regarding the nature and primacy of science objectives.

D. Funding for Research

The operations budget for the Space Telescope includes funding for: contract operational personnel at Goddard Space Flight Center; the Space Telescope Science Institute and its personnel; ground systems development; and research proposals. The Subcommittee expressed concern that this budget structure may lead to a competition between science funding and that required for the health and operation of the observatory itself. During questioning, Mr. Keller testified that the operations budget will be held to $50-60 million during the post-launch era. The Subcommittee sought assurances that the science funding would not simply be the remainder after accounting for the operation of the observatory.

In discussing the mechanism for funding proposals the following dialogue took place between Rep. Bill Lowery (R-CA) and Dr. Hinners:

Mr. Lowery: Is it the intention to lump them (proposals) into a budget line item? And what happens if the Institute or the Goddard cost actually increases? Does science get less . . ? They get whatever is left over?

Mr. Hinners: That refers back to what Mr. Keller was saying, that what our objective is is to contain, restrain what we call the operations cost, which then means that for a given budget more dollars go into supporting the observations or the data analysis.

Mr. Lowery: You're going to restrain your overhead costs, then?

Mr. Hinners: That's correct.

Speaking as a user of the Observatory, Dr. Bless provided an additional perspective in emphasizing that the ground control system should be considered dynamic and amenable to changes which may increase efficiency and lower costs. He said:

> "With a given operations budget, every position by which the staff could be reduced would mean that roughly one additional major user of ST could be funded. Thus, any measure by which the operations and support staff could be reduced without unduly impairing ST's operational efficiency would be very important."

Drawing upon his experience with the International Ultraviolet Explorer, Dr. Bless alluded to the rapid advancement of computer-based remote access technologies and explained:

> "In this context, many of the support functions of the Institute might well change significantly in character in the future. The Science Institute could, in principle, have been located anywhere in the U.S. As it turned out, it is near the Goddard Space Flight Center. It would seem to me to be worth careful study to see if any advantage might be taken of this some time in the future. Many more possibilities will undoubtedly appear as time goes on, which might lead to a more efficient ground system and even possibly to a smaller operations staff."

He summarized his views by saying, "Thus, no part of ST's operations and management should be considered immune from any changes which, in balance, would increase the scientific productivity of the observatory."

During the hearing, several witnesses referred to the number of general observers which could be accommodated by the Observatory. Although NASA originally planned for 200 scientists per year, the possibility exists that more could be accommodated through proper management of the observing schedule. The Subcommittee sought to place this in a budgetary perspective. In response to a request by Mr. Lowery, the following material was submitted by NASA for the record:

> "The Space Telescope post-launch operations funding level is currently estimated at approximately $50-$60 million per year (FY 1985 dollars). We estimate that the Research Support (Science Investigations) will require 30-50 percent of the post-launch operations funding or $15-$20 million based on support of approximately 200 observations programs per year. Based on this information, our best estimate of the funding required to support 600 observation programs per year would be an increase on the order of $25 million annually or a little more than double the baseline cost. In addition, there would be about $6 million of non-recurring cost associated with support requirements such as purchase of equipment, etc., for the additional observation programs.

Despite NASA's intent to constrain costs in each overhead category, it is likely that pressures will arise to increase expenditures as the true nature of the operations program becomes clear. There would be value in NASA determining in consultation with the Science Institute the optimum number of investigators that could be funded and in establishing some mechanisms whereby this funding will be protected from other cost increases.

E. Applicability of the Institute Concept to Other Future Observatories

Inasmuch as other astronomical observatories such as AXAF and SIRTF will be in operation in the early 1990s, the Subcommittee examined the applicability of the Institute concept to other such facilities. Their permanent character, complexity of operations, and broad scientific appeal resemble the Space Telescope in many respects. Therefore, it may be appropriate to consider some form of data management and operations different from that used for short term mission-based programs. Given that both AXAF and SIRTF will be beginning their development phase within two years and the science community should be involved, as with the Space Telescope, in design tradeoff decisions, any such institute would need to be established soon.

Chairman Volkmer directed a question to Dr. Field regarding the general applicability of the Institute concept to other observatories. Dr. Field replied:

> "Well, in my opinion, Mr. Chairman, if the Space Telescope Institute is successful in providing a good and fruitful interface between the community and the project, then almost certainly it will be discussed as a possible model for any future projects along this line, but I think it's too early at this point to make a judgment."

In a similar manner, Dr. Bless was asked by Chairman Volkmer whether the Science Institute itself might serve in the same capacity for other observatories:

> "I would agree with what Dr. Field said, that it is too early to judge how well the Institute idea is working, so we really can't say. I think even if it worked well, there might be a certain reluctance among astronomers in general to have the same organization running several major observatories . . . . With the best will in the world, it might appear that too much power, too much is being concentrated into one institution, so there might be more or as much of a political problem, a problem of perceptions, as anything else, were that suggested."

Speaking as a private individual rather than as chairman of the Institute Council, Dr. Spitzer added that one could point to advantages

> ". . . of combining all these institutes into one -- advantages in principle of communication and cost reduction, et cetera, et cetera. My own feeling is strongly against combining all these institutes. I have a prejudice against large organizations devoted to pure science. Some of them are, in fact, very successful but I have the impression that the problems of communication are exacerbated. There are advantages of a pluralistic society in

> science, as indeed there are in our country, and I would personally hope that if there are other institutes they will be kept separate, they will be scattered around the country, and that they will not all be concentrated in one large, ponderous, possibly unwieldy organization..."

The NASA view was articulated by Dr. Hinners in material submitted for the record:

> "The success of the Institute concept cannot be demonstrated until the Space Telescope has been operational for some time. Since the adoption of the Institute concept (7 years ago), the astronomical community has participated in the very, very successful International Ultraviolet Explorer (IUE) experience and technology has taken dramatic strides toward permitting remote access to and distribution of data. Consequently, I believe that the currently defined scope of the Space Telescope Science Institute is no longer appropriate for planning toward the science programs of the 1990's."

Thus, the Subcommittee was left with the sense that the scientific community may not favor the enlarging of the Science Institute for other observatories. Yet, clearly the need exists to consider the type of infrastructure that will be needed for the 1990s, and the economy of operations that may be achieved through existing institutions should be a consideration.

F. Remote Access Technologies

A major factor in the original recommendations for the Science Institute was the perceived need for investigators to interact closely with the NASA communications and control organizations. When the Hornig report was published in 1976, the most feasible approach to establishing this interface was to colocate the investigators and the operations personnel.

At the hearing, the Subcommittee examined the potential needs and capabilities for establishing an infrastructure whereby other sites could gain access to operational and observational information from ongoing observations or archives. Such an infrastructure could be of use for future facilities such as AXAF and SIRTF and eventually reduce the overhead expenses associated with data management. This could also eliminate the need for astronomers to take up residence at locations removed from their principal place of research and lead to a strengthening of university-based astronomy departments.

In his opening statement, Rep. Manuel Lujan, Senior Republican Member of the Subcommittee, said:

> "Clearly, a more permanent facility gives scientists a larger role than before in the space science programs, which have been dominated by engineers at NASA. The Science Institute will serve as a focal point for scientists from all over the world. However, it is not clear to me that the scientists will actually have to physically be at the Science Institute. The recent example of the International Ultraviolet Explorer may set the right precedent for the future because in that program scientists have taken advantage of the recent advances in computer and communications capabilities such that they can remain at their own universities or other institutions and interact with the observing facility very effectively. This would be an exciting way to encourage wider use of the data at the same time we save money."

Chairman Volkmer inquired of Dr. Spitzer whether the actual presence of the investigator at the operations center would be an absolute necessity. Dr. Spitzer replied:

> "The difficulty is, we have had extensive experience with guest observers with the Copernicus satellite, and at least at the beginning when observers started to use Copernicus for their own programs, it was really absolutely necessary that they come to Princeton and talk with our own -- with the Princeton astronomers -- just to understand what is possible with the instrument and what wasn't, and in what form the data emerged and how it should be analyzed. . . There is an educational process that is required before one can make effective use of a complex instrument."

Dr. Bless compared the Space Telescope's operations with those of the International Ultraviolet Explorer (IUE) with which he had experience:

> " . . . unlike the users of IUE, the general observers on ST will not have much opportunity to observe in real time, nor is the IUE observing mode likely to be utilized by ST. That is, observers will not be assigned blocks of observing time. Rather, parts of one observing program will be interspersed with others, and it will be impractical for users to be at the Institute when all of their data are being collected by ST, so after one or two trips to familiarize themselves with ST procedures and people, it is quite possible that many users would rarely return to the Institute. Thus, it is not obvious to me that after a time the general observer workload of the Institute will be as large as is presently estimated.
>
> A much more important consideration, however, is that the technology by which computers can communicate with each other and by which large amounts of data can be stored is advancing rapidly. There have been experiments in ground-based observing from remote sites which have been successful, as have similar experiments with IUE. There seems little reason to believe that such arrangements would not be practicable for users of ST. Even real-time observing could be done remotely, as well as much interactive data reduction and so forth."

Dr. Bless further elaborated:

> "I agree with what Dr. Spitzer said. At the beginning, it's absolutely necessary that observers go, become familiar with the practices and procedures, people and so on. That you have to do.
>
> My point was that after a trip or two of that sort to gain this familiarity, then it may . . . not [be] necessary to visit the Institute as often, and much of the exchange of information, of observing requirements, of communications and so on, could be done by computer or whatever . . .
>
> . . . The whole gist of what I'm trying to put across is that ST is supposed to be very long-lived, so it behooves us to think of not just our immediate problems, which of course we all are preoccupied with, but to look down the road quite a bit for 5, 10, 15 years ahead of time to see, to try to imagine what changes might occur and how we might make the Institute more efficient in its operations of ST."

In response to written questions regarding the necessity for the investigator to be co-located with the operations personnel, NASA submitted the following material for the record:

> "For real-time observations (which are estimated to be about 20 percent), it is very important for the observers to participate directly and interact with science operations to support their research. Ground observatories and IUE have operated this way almost exclusively in the past. There is a growing trend both with IUE and ground observatories to observe remotely, with the investigator remaining at his/her home institution and being in contact with the operating site only by telephone or data link. For the majority of observations with Space Telescope (because they will need to be pre-planned and automatically executed by the on-board computers while Space Telescope is not in communications status with the ground), it is unnecessary for the observer to be on site. However, for non-technical reasons, we expect even these observers to come to the Institute at least once and perhaps several times. In most cases, we anticipate there will be a strong desire on the part of the users to conduct more and more of their data analysis and interpretations at their home facilities."

The Subcommittee also requested that NASA describe their plans for establishing a high data rate transmission capability for remote access users of the Observatory. Their response was as follows:

> "The accommodation of the remote users during the data analyses phase of the observations with Space Telescope is a highly desirable direction. These concepts are not new to us, but they are taking on exciting new dimensions as a result of advancing technology. Both the ongoing development of the Science Data Analysis System and the study effort of the Data Archive and Distribution Services (DADS) for Space Telescope can easily accommodate remote users. The transportability of applications software, as well as data to the remote user sites, is contemplated. The DADS planning assumes low data rate transmission capability, and we have a commitment to share data with our European associates."

G. Further Development of the Science Operations Ground System

The Science Operations Ground System (SOGS) includes the hardware and software essential to linking science objectives to the operation of the spacecraft. It schedules observing time and sequences and generates operational commands.

During the hearings, the Subcommittee was made aware of several improvements in SOGS which must be made before the full potential of the Observatory is realized.

In commenting on the reasons for past growth and potential future growth in the operations budget, Dr. Spitzer said:

> "The SOGS system, as it was being built by TRW, really made no allowance for following planets. That's much more difficult because planets move with respect to the stars, and that is entirely different, and it just hasn't been included . . . in the way SOGS is now being built, so there has to be a post-SOGS program of development for controlling the Space Telescope so that it can look at a particular area on Jupiter for several hours and follow it while Jupiter rotates and moves with respect to the stars. That all costs money and takes more people.
>
> . . . there are also difficulties in the use of the Space Telescope for what is called astrometry -- measurement of the precise positions of stars with respect to each other. This is done in principle with the fine guidance sensors that Perkin-Elmer has been building. The data for those fine guidance sensors is regarded by the engineering staff as engineering data, so it doesn't really get into the SOGS system at a place where it's useful . . . the output of SOGS doesn't include data that the astrometrists can really use. So in addition to modifying SOGS to follow the planets, we also have to modify SOGS to include the astrometric data. Those are the two main modifications . . ."

Notwithstanding these deficiencies, Dr. Bless testified that the system planned for launch would be adequate:

> " . . . TRW, with considerable help from the ST Science Institute and the Goddard ST project, has come a long way in developing the Science Operations Ground System. It appears that a workable system will be in place for the launch of ST."

These needed improvements were also described by Dr. Hinners in his prepared statement as part of an overall planned upgrade of SOGS.

"There is agreement, I think, that we will have a SOGS system which will be available and operating and will support your early launch of the Space Telescope in good shape. We realize that the SOGS system that is now under development will not be the complete system, the final system.

We are looking at an evolution of the SOGS system for two reasons: One, we do not now have the funding or time, probably, to complete that system. Examples are the complex moving target selection and some of the software systems involved in the astrometry. Those will be implemented in an evolutionary fashion up to and during, after the launch period.

We also know that in the instrument development, the instrument operation, when we get down to operating, and a software checkout, when we get on orbit, that new things come up, new ways of operating. So we expect and anticipate a steady evolution of the science operating ground system."

The Subcommittee also examined the funding structure for these improvements in order to determine whether other portions of the operations budget would be penalized. Dr. Hinners explained:

"We have the initial SOGS development now well scoped, the schedule understood. So I view the other change as part of what we call a SOGS maintenance and evolution. As we learn more about its use in the early operations of the Telescope, and we'll find new things to do with the Telescope which will then require updating and upgrading of the software."

Thus, the Subcommittee was assured that these improvements could be made after launch within the planned SOGS maintenance budget.

H. Orbital Insertion and Reboost

A major objective of the hearing was to examine the relationship between the Space Telescope (and similar permanent science facilities) and the Space Transportation System. In order to establish and preserve the science capabilities of the observatory throughout its useful life, a minimum level of logistical support will be required from the present fleet of Space Shuttles and from the future system including the Orbital Maneuvering Vehicle, the Space Station and improved shuttles.

Mr. Nelson questioned the NASA witnesses on the capabilities of the existing Shuttles with integral fuel tanks to accomplish orbital insertion and reboost operations. The following dialogue took place:

Mr. Nelson: . . . you need to put [the telescope] up about 320 miles. Now, what do you need to do to the Shuttle to reach this altitude?

Mr. Lucas: We don't need to do anything to the Shuttle to reach that altitude. We expect to put it at that altitude by direct injection from the Shuttle to 320 nautical miles. That will be a single payload, however, it will take the capability of the Shuttle to do that.

Mr. Nelson. And that is using the 110 percent engines?

Mr. Lucas. No, sir, it will not be using the 109 percent engines. It will not -- I believe it will not require the 109 percent engines. 104.

Mr. Nelson. Any lightened orbiter, such as the filament wound casings, or anything? Just go in with what you have.

Mr. Lucas. That is right, sir.

In further discussion, Mr. Nelson continued to examine the reboost frequency.

Mr. Nelson: All right, if we wanted to reduce the frequency of that reboosting, what could we do?

Mr. Lucas: We could, of course, put it to a higher altitude, but that would require us to reboost less frequently. We hope, of course, that with the coming availability of an orbital maneuvering vehicle, which would be stationed at a space station, for example, that this reboosting would be a very simple matter, and would not require the Shuttle.

Inasmuch as the orbital maneuvering vehicle will not be available until the early to mid 1990s, Mr. Nelson pointed out that supplemental Shuttle capabilities available with Shuttle orbital maneuvering system add-on kits may offer a near-term approach to higher and less frequent reboosts. In response, NASA submitted the following material for the record:

> "The original approach to meet anticipated requirements for orbital altitudes above the basic Shuttle orbiter was the OMS Payload Bay Kit. This approach was never implemented because only two payloads in the STS mission model had requirements beyond the standard orbiter OMS system: the Solar Maximum Repair Mission and the Space Telescope. An alternative mode, the direct insertion method (longer SSME burn), was selected to satisfy effectively these missions without the significant additional development cost of the OMS Payload Bay Kit. In the case of the Space Telescope, the plan is to launch the spacecraft into a 320 nautical mile orbit, and use the Orbital Maneuvering Vehicle to reboost the Space Telescope when the orbit decays to about 300 nautical miles. This is currently estimated to be in the late 1988-89 timeframe based on predicted solar activity."

Thus, it was implicit in the NASA testimony that the predicted solar activity will determine a need for the OMV by 1988. Higher than average solar activity, such as was the case during the orbital decay of Skylab, will determine an earlier need.

The Subcommittee also requested that NASA describe the risks involved with revisits to the observatory and reboost operation. Their response was as follows:

> "Some of the risks which are associated with a Shuttle visit to the Space Telescope are:
>
> 1. Contamination from proximity Shuttle operations.
> 2. Malfunctions in the retraction and redeployment of appendages such as solar arrays and antennas.
> 3. Mechanical damage from inadvertent contact (Remote Manipulator System or EVA-induced).
> 4. Unforeseen thermal conditions/attitudes.
> 5. Erroneous EVA techniques.
> 6. Failure to relatch Space Telescope doors.
>
> All of these risks have been analyzed and the probabilities of occurrence are assessed as very low.

The risks associated with reboosting the Space Telescope include the first three risks identified with a Shuttle visit. In addition, there are some potential dynamic loads risks associated with the Space Telescope reboost. However, our current assessment showed the probability of adverse effects, particularly when compared to the shortened lifetime of the Space Telescope, to be acceptable."

I. Maintenance Philosophy

In his opening statement, Chairman Volkmer stressed that the Space Telescope is the first of a new generation of permanent science facilities. He emphasized that it is important to determine the true meaning of the concept of permanence. He said:

> "I believe that [permanence] must encompass not only longevity in space but also continuity in scientific return. What must we do to ensure that the full scientific potential of the observatory is realized throughout its lifetime?"

It is clear that maintenance operations bear a direct relationship to the science return from such facilities. The maintenance philosophy must encompass compromises between costs, number of spare parts, Shuttle capabilities, and the risks associated with the operations themselves.

Mr. Nelson questioned the NASA witnesses on the general maintenance plan. The following dialogue took place:

Mr. Nelson: Under what circumstances do you think that you would come back and revisit the observatory for maintenance?

Mr. Lucas: . . . If we have some indication of the deterioration of some of the systems, or if some system becomes nonfunctional, then we would of course revisit and make appropriate repairs.

Mr. Nelson: Are you likely to experience any of those malfunctions?

Mr. Lucas: In time, we most certainly, I think, will. We, at the outset, when we planned our maintenance and refurbishment program, we anticipated that in about two and a half years . . . because that was the time associated with the anticipated life of the kinds of components that would be built in.

And usually, our experience has been that spacecraft systems last longer than we planned for, but certainly, in time, they will deteriorate.

The Subcommittee requested that NASA submit estimates of the number of equipment failures (downstates) that would require a revisit by the Shuttle under the current plans. NASA's response is as follows:

> "The likelihood of downstates is derived from a mathematical model, which considers the number of parts, systems redundancy, duty cycles, projected failure rates and orbital replacement capability. This math model, which is based on current maintenance and refurbishment planning, indicates that over a projected life of 15 years, the Space Telescope may have about nine downstates.
>
> a. These downstates could result in a nonoperational Space Telescope for approximately 30 percent of a 15-year assumed lifetime, therefore, or a potential of 30 percent loss of science viewing time. Also, some programs requiring an observation continuum time may be affected, depending upon when a downstate occurs. The interruptions would particularly interfere with investigation of invariable and periodic astronomical systems, such as Cepheid stars, that are fundamental indicators of astronomical distance.
>
> b. Based on the above, as many as nine Space Shuttle missions might be required to support the maintenance and refurbishment activities necessary to correct the downstates. Some of these missions could also accomplish required reboosts. We are currently reassessing the maintenance and refurbishment goals because it appears that more extensive on-orbit Shuttle repair, or alternately Space Station, could reduce the maintenance and refurbishment costs."

Chairman Volkmer solicited the views of Dr. Bless on a preventive maintenance concept wherein units are replaced based on their predicted failure rates rather than after failure. The following exchange took place:

> Mr. Volkmer: Do you think it would be practical to develop a preventive or scheduled maintenance program? You know, we look at a lot of other projects that we have, our own personal vehicles [on which] if you do certain maintenance that is scheduled along . . . you may be better off rather than waiting for something to go wrong. Is it possible to develop such a thing for the Space Telescope, to anticipate problems beforehand?

Mr. Bless: It seems to me that in a couple of areas it would be possible and perhaps even necessary to do so. I refer in particular to the power systems. If the batteries failed or if the solar arrays failed, the instruments there and all the equipment would get cold, and it is not clear how many could survive the temperatures which might be reached without the active thermal control that now exists. Therefore, one would risk the danger of losing the entire observatory if something happened to the power system, so that would be one thing which I think should be considered, should be studied for preventive maintenance, if you will.

There could be value in a reexamination by NASA of the preventive maintenance concept. Not only might this minimize the science lost but it might also avoid reprogramming actions and other budget impacts which may be made necessary by unplanned visits to the observatory for maintenance purposes.

J. Science Instruments -- Maintenance, Refurbishment and Replacement

Strongly related to the maintenance philosophy for the spacecraft, the science instruments must be considered an integral part of the long-range maintenance plans. The Subcommittee sought to examine the extent of planning undertaken for the maintenance of the observatory's science instruments and their schedule for replacement.

Dr. Bless, in his opening statement, reflected concern that not enough emphasis has been given this aspect of the Space Telescope program. He testified:

> "Let me address the maintenance and refurbishment program by which we all hope that Space Telescope will remain a productive observatory for many years. Originally, over 100 boxes on ST, including the scientific instruments, were to be replaceable on orbit. For budgetary reasons, this number fell to about a dozen, but over the last year has increased. The emphasis so far has been on identifying those critical spacecraft or telescope subsystems with the lowest inherent reliability and scheduling replacement units to be constructed ... the scientific instruments -- though still units which could be replaced on orbit -- have not been included in this planning ...
>
> One concern our group has is that so far the M and R program has apparently taken the approach of keeping the spacecraft and the telescope operational rather than of maintaining a productive astronomical facility. It is not clear that a broader approach would result in the same strategy as the one currently adopted. No guidelines exist at present. Perhaps NASA should establish Level 1 requirements for the M and R program."

During the course of the hearing, it was established that the schedule for instrument replacement currently envisioned by NASA will result in two new instruments within six years after launch and two additional instruments within nine years after launch.

Thus, one instrument would need to remain functioning at least nine years in order to retain the full science capability of the observatory. This led Chairman Volkmer to question Dr. Bless regarding the on-orbit repairability of the existing instruments should they malfunction. Dr. Bless testified:

" . . . Unfortunately, the present instruments were not designed with that capability in mind. They were designed to be replaced as a unit, so it would depend critically on which element within an instrument failed. If we were lucky, it might be that an electronics box which was easily accessible by simply removing one panel would be the culprit, and in that case it is conceivable that it could be replaced, but in general I think that would be a rather lucky happenstance which we shouldn't count on."

Chairman Volkmer also pursued this question with NASA witnesses. The following dialogue took place:

Mr. Volkmer: . . . Are there any of the instruments that we would be able to repair in orbit?

Mr. Hinners: The instruments by and large are not repairable on orbit. The initial design concept was to replace entire instruments in those packages. Getting inside those packages and working with the innards is a tough job right here in our terrestrial laboratories. Again, sometimes we get very inventive when faced with a problem, but by and large we are looking at a replacement of those units.

Mr. Volkmer: Bringing the whole instrument down and taking one up --

Mr. Hinners: Either taking one up and replacing it with another instrument on that same flight or, if necessary, putting in the structural thermal axial replacement unit as a dummy while it's brought back, repaired, then taken up again.

Mr. Volkmer: So that would be for the axial but not for the radial type?

Mr. Hinners: That's correct. We do not have a replacement or a backup for that radial at this time.

On the question of ground return for repair operations, Chairman Volkmer questioned the NASA witnesses on the availability of spare parts, manpower, and general contingency plans for the repair. It was clear that no formal plans now exist; however, the NASA witnesses testified that this is an area of active discussion and that a recognition of the problem exists.

Chairman Volkmer also solicited NASA's views on the likelihood that the instruments will actually last until replacements are available. Mr. Keller testified:

> " . . . We very seldom design a lifetime of more than three years. You'd normally find those kinds of lifetimes. However, there was a recent study done by the people at Goddard which indicates that the one thing that does not normally fail on a spacecraft is the instrument. We have had instruments lasting in general much longer than the spacecraft. There with five instruments, one could develop a statistical probability of failure, and about the only thing I could tell you is that's not the date it would fail on.
>
> We have a relatively small number of instruments here, and I think it is not unreasonable to suspect that the majority will last for a good many more than three years."

Mr. Keller also pointed out that the synergism between various instruments plays a major role in determining the loss to science from specific instrument failures.

The Subcommittee also received testimony that some benefits might be gained from producing a duplicate of the Radial Wide Field Planetary camera. Dr. Bless stated:

> "It is generally recognized that of the instruments on ST, the wide-field camera is quite special in many ways. It is an extremely powerful camera. It provides unique operational support to the other instruments. It will provide the data of greatest interest and excitement to the general public, who have, after all, paid for ST. Finally, of all the instruments, it is the only one which would be rebuilt today essentially as it was constructed originally, in large part because of its superb detectors.
>
> For these reasons, the Science Working Group recommended last February that a backup wide-field camera be built. This should be started as soon as possible so as to take full advantage of the availability of key JPL people who built the first wide-field camera. This recommendation is presently being considered by the project."

The NASA witnesses reflected this general view and testified that a decision was in process. Although it is possible that the instruments will continue to function until a complete set of replacements are available, great potential exists for lost science due to early instrument failures.

K. On-Orbit Refurbishment

Since the beginning of the Space Telescope program, NASA's plans have been to return the observatory to the ground for an overall refurbishment five years after launch. The Subcommittee wished to examine the costs and risks of such an operation and any alternative plans that might exist. The Subcommittee also sought to examine the impact of recent events such as NASA's Space Station initiative and the repair of Solar Max on the refurbishment plans. In his opening statement, Mr. Lujan said:

> "The Space Telescope marks a new era in science. Perhaps the repair of the Solar Maximum Mission was really the starting point of this new era because it shows the feasibility of "permanent" observatories in space that can be serviced and repaired in orbit. In fact, these new facilities in space can be upgraded in orbit since they have been designed to allow replacement of instruments with newer versions at some point in time. It is cheaper and less risky to repair or refurbish in orbit than to bring the facility back to earth, or to launch a new one built from scratch. Of course, this is another area where the Space Station will play an important role. These capabilities will have great implications in regard to not only the cost and design, but the institutional structure as well."

In dialogue with Dr. Bless, who alluded to the use of the Space Station for refurbishment, Chairman Volkmer sought clarification of the five year milestone in relation to the availability of the Space Station. The following exchange took place:

Mr. Volkmer: ... you addressed the problem of refurbishment. Is it not envisioned that the refurbishment, the first part, should take place within about five years of launch, which would be 1991?

Mr. Bless: That was the original schedule, yes. I'm not sure to what extent people are still considering that particular schedule.

Mr. Volkmer: In the first place ... I think the possibility is fairly remote that we will have a Space Station in operation [that] could actually do the refurbishment by 1991. We are going to have to face that.

Mr. Bless: That's right, but we hope that ST might last until the turn of the century, in which case the Space Station perhaps could be useful in that regard.

Mr. Volkmer: I agree with that, maybe by 1996 or 1995 or somewhere along in there, but then we're talking about that 9-year frame and not the earlier.

Mr. Bless: It may well be that if we have some early mortality with the instruments, with one or more of the instruments, that we will probably or might well have to simply take our lumps and operate without them.

Chairman Volkmer also questioned the NASA witnesses regarding their intent to return the observatory for a five-year ground refurbishment. Mr. Keller testified:

" . . . the specific answer to your question is no. The details are still being worked. The reason I say the specific answer is no is that it would, I am sure, be a longer period of time than five years if we were to bring the telescope back.

Now, you will recall that in the rebaselining activity, we have added a number of orbital replacement units that were not there before . . .

Further, we have not been able to totally evaluate this yet. The experience that we achieved on the Solar Max repair mission would indicate to us that we have a capability to do much more than we had planned. A number of the activities that were conducted successfully on that mission were with systems that we would not describe as orbital replacement units. So we can do more than we thought.

The third thing that enters into this is, as a part of the Space Station program, ultimately we will achieve the on-orbit capability. Perhaps more importantly, in conjunction with that program we will develop more advanced astronaut suits and things of this nature that will, even though operating from the Shuttle, give us more flexibility and more capability to do things that have not been planned.

We are in the process and have underway a study now to review the Space Telescope and try to identify, based on some assumptions as to what a Space Station capability might reasonably be, are there any particular units that could not be replaced on orbit, or repaired . . .

... And we would hope within a reasonable period of time to come up with an assessment of the validity of what I would characterize as at least an objective now, which is to develop a plan to not bring the Telescope back, to not expose it to the hazards of a relanding activity, and not expose it to the potential contamination of ground operations."

The Subcommittee sought additional materials from NASA concerning the rationale for the five year milestone, the nature of the refurbishment operations and the consequences of delaying this milestone. NASA's response is as follows:

A. During the Space Telescope Phase A&B studies in the 1970's, best estimates of parts reliability, systems complexity and design redundancy were made. Based on projected failure data, a five year life expectancy was predicted. Subsequently, this requirement was included in all ST contractor end-item specifications as a basis for establishing hardware reliability goals.

b. The basic Space Telescope ground refurbishment requirements originally established were as follows:

1. Replace non-orbital-replaceable hardware
2. Refurbish optics
3. Replace insulation
4. Refurbish thermal control coatings.

Further studies defined a KSC-based ground maintenance operation which could consist of the following:

1. Replace degraded/failed components (orbital-replaceable or other).
2. Incorporate any new science instrument(s).
3. Perform systems level testing and re-launch.

c. Based on our current understanding, we believe it will probably not be practical to perform major optical refurbishment on orbit, but many other types of on-orbit refurbishment may be possible. We are putting together a team of people to study the potential refurbishment problems that may be encountered and compare those to the current and planned Space Transportation System capabilities so that we can conduct as many repair/refurbishment activities on-orbit as possible.

d. The original Space Telescope major refurbishment milestone was based on conceptual analysis. However, the need for actual refurbishment will be determined by actual hardware (non-orbital-replaceable) failures. The ground return would be initiated only if no on-orbit work-arounds could be identified, and only if the potential marginal benefits justify the cost.

NASA's current intent to accomplish refurbishment on-orbit represents a major departure from past plans. The impact of Space Station design and availability are major factors which must be considered. Furthermore, any strategy for prolonging the refurbishment milestone which involves engineering changes to allow for orbital replacement units must be compatible with the remaining assembly and verification schedule. On the whole, the Subcommittee did not gain significant insight into the refurbishment plans and operations that it sought during this hearing.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Based upon the testimony and views expressed during the hearing, this section summarizes the Subcommittee's findings in several areas.

A. Present Status and Health of the Space Telescope Development Program

The Subcommittee is greatly concerned that a seven year, $1.2 billion program should entail such risk in its final development stage. The Subcommittee has monitored the progress of NASA and its contractors in resolving many of the technical difficulties which have arisen during the project's life. NASA's initiatives in restructuring its management approach to the program and establishing an independent performance assessment team have served to focus attention in critical areas.

A question which was central to many of the development issues examined in the hearing was the possibility that the Space Telescope would be launched without meeting all of the prime design requirements if problems arose which could not be resolved within the existing schedule. The hearing demonstrated that the additional costs of up to $10 to $12 million per month of delay in the launch date could strongly influence the decision to maintain the schedule despite the potential loss to science. However, no specific problem was identified in the hearing which would give insight into the real probabilities that this would occur.

In a broad sense, NASA has taken extraordinary measures to maintain adherence to the established design requirements and operational plans. This has in some cases entailed substantial additional costs to the program. There is also ample evidence that NASA has involved the science user community in an advisory capacity in adhering to these requirements and plans. The Subcommittee has not found, however, that an adequate mechanism is in place to ensure that critical design and programmatic decisions made in the Space Telescope project have been properly balanced against the needs of the entire Physics and Astronomy program.

The segment of the scientific community which will be prime users of the Space Telescope probably will strongly support decisions in favor of maintaining the highest quality observatory, while other scientists might be more willing to consider compromises. NASA should ensure that balanced advice is solicited from the scientific community. The question posed should not be "does the scientific community wish the Government to commit its resources to maintaining the observatory's design requirements?" The real question is, "Given the likelihood of a limited budget, are the observatory's design requirements and plans as important as other major programs which are also competing for the same resources?"

The most substantive deficiency identified in testimony is the assembly and verification phase for which sufficient detailed planning does not exist. This problem is made all the more acute by the minimal slack time available for resolving unanticipated difficulties. Together these findings suggest an inappropriately high level of risk associated with this crucial phase in which all systems integration must take place.

The Subcommittee recommends that NASA, in consultation with the appropriate existing advisory groups, prepare and publish an analytical review of Space Telescope development as an aide to the management of future large science programs (and perhaps the Space Station). This review should be published by February 1, 1985.

B. Responsiveness of the Observatory to Its Users

The Subcommittee has long been interested in the Space Telescope project as an experiment in establishing innovative plans for serving a broad user community and involving the user community in critical program decisions. A major element in these plans is the interface provided by the Space Telescope Science Institute. The Subcommittee is cognizant of the organizational and managerial difficulties inherent in the NASA-Science Institute relationship.

All witnesses were in general agreement that the scope of responsibilities for the Institute has now been adequately defined and that the general intent of the Hornig report has been fulfilled. Clearly, however, early planning efforts for the ground operations were inadequate and as a result, the full array of tasks which needed to be carried out was not defined for the Institute, nor for Goddard. Thus, a major reason for the growth in size and cost at the Institute has been due to the tasks not originally identified.

One major area of the Hornig report which has not been fully implemented is the Institute's role in advising NASA on design decisions and refurbishment policy which may affect the science return. In large part this is due to the delay in establishing the Institute. In lieu of this, NASA has established alternative ad hoc mechanisms for soliciting technical advice from the scientific community. Clearly, long term issues, such as maintenance and refurbishment decisions, will require a permanent institutionalized framework for involving the scientific community. This can best be done by utilizing the Science Institute in the decision process.

With respect to the Institute's role in setting priorities among science objectives for the observatory, the Subcommittee finds that the Institute's role and approach is reasonable and appropriate. The utilization of user groups in defining the objectives of the science program will ensure that the best interests of science will be served.

The Subcommittee is concerned about the structure and mechanism for funding proposals. Inasmuch as the support for science is included in the overall operations budget, and this overall budget probably will be constrained to $50-60 million per year, a direct competition is established between the day-to-day operation of the observatory and the science that will result. Any growth in other segments of the ground operation system may result in a diminished source of funds for science. Although the NASA witnesses testified that their goal is to constrain each cost element within the operations budget, past experience has demonstrated a tendency toward cost growth due to tasks and system improvements deemed absolutely essential. The Subcommittee believes that the science funding should take into account the number of researchers that can be accommodated and the cost of proposals rather than merely being what is left over after the operation of the observatory is accounted for.

The Subcommittee also wished to examine in depth the applicability of the institute concept to other future observatories. Although planned future observatories are comparable to the Space Telescope in their complexity, their long-lived nature, and their scientific merits, the witnesses were indecisive in endorsing the general applicability of the Science Institute concept. Overall, there was a cautious-to-negative reaction towards enlarging the scope of the Science Institute to include other observatories although the economy of service might be advantageous. Some witnesses, however, maintained the view that an independent entity managed by astronomers and responsible for science operations would be of value for large observatories such as AXAF.

Thus, the hearing provided little useful information on this important question. The Subcommittee believes that it would be of great value for the scientific community to examine its needs for the type of science operations support and data management services that will be provided by the Science Institute for the Space Telescope.

A related issue which was examined in the hearing was the potential utility of remote access technologies to supplant the need for researchers to be physically colocated with operations personnel. Although some initial on-site orientation may be beneficial, the witnesses generally agreed that many observing and research functions could be addressed by a remote access infrastructure such as was the case with the International Ultraviolet Explorer satellite.

In its response to the original Hornig report, NASA rejected the notion that a system of microcomputers linked to various centers around the country should be established in order to facilitate more efficient access to observatory data. NASA stated its belief that this would dilute the nature of the interface between the Science Institute and the operations center personnel. Additionally, this would work to the detriment of establishing the Institute as the science operations center. In view of the experience

gained with other satellite observatories since the Hornig report was written, NASA should reexamine this issue taking into account the utility of such an infrastructure for future observatories.

Because of the growing capability for remote observing and because observers will become familiar with Space Telescope procedures, it seems that the number of guest observers present at the Science Institute may peak in the first year or two of operation, and plans for facilities should be made accordingly.

The Subcommittee recommends that NASA and the Space Telescope Science Institute continue to work together in consultation with the scientific community to ensure that the $1.2 billion investment in Space Telescope returns ample scientific dividends. Particular attention should be given to ensuring adequate research funds as well as opportunities for "remote observing".

The Subcommittee further recommends that NASA in consultation with the appropriate existing advisory groups consciously document the early operations of the Space Telescope Science Institute with a view toward producing and publishing an analytical report that will aid such future space science activities.

C. Post Launch Operations, Maintenance and Refurbishment

A major objective underlying much of the Subcommittee's oversight interest in the post-launch era was the examination of the interaction between the observatory and the Space Transportation System infrastructure and the Space Station. Clearly, maintenance, repair and refurbishment of permanent science facilities will be a significant requirement for future space operations and systems. These operations and systems should be planned with the goal of maximizing the science return from these facilities.

On the issue of orbital insertion and reboost, the Subcommittee was not fully satisfied that NASA's organizational and institutional structure fosters a sufficient level of cooperation and communication between science and operational interests. For example, the rendezvous and reboost of satellites clearly requires a substantially more versatile Space Transportation System than is presently available. Yet, the decision to enhance the Shuttle's performance characteristics with, for example, auxiliary orbital maneuvering system kits, does not appear to be strongly influenced by science needs. Such a system would increase the altitude at which the observatory could be placed, thereby reducing the number of reboost missions required.

Inasmuch as many of the past developmental problems appear to be resolved and the post-launch phase is imminent, the Subcommittee intended to examine NASA's plans and policies for maintenance and refurbishment. The NASA witnesses were generally vague in discussing these issues but testified that these considerations were in a planning stage. Nevertheless, the fundamental philosophy underlying the maintenance program apparently will be one in which a visit to the observatory will be undertaken only if a system has failed or is in the process of failing. Given the lead times involved, this implies that a significant amount of science could be lost before the repair is made.

Although this approach may well minimize the number of Shuttle revisits, and hence costs, it also assures that the science return will be diminished. A significant question left unanswered by the hearing was the feasibility and merit of a preventive or scheduled maintenance program in which items are replaced based upon their figures of reliability. In such a program, systems would be replaced before they fail, so the loss to science would be minimized. Compelling testimony was heard that at least some elements, such as the power systems, should be approached from a preventive maintenance standpoint in order to ensure that irreversible damage is not suffered by the scientific instruments in case of failure. The key question, then, centers on the affordability of such a concept and the extent to which it can be implemented.

With regard to the maintenance of the science instruments, the Subcommittee finds that the infrastructure now in place will not easily support a ground-return/repair plan nor is it likely that these instruments can be repaired on-orbit. Furthermore, the schedule for replacement of the instruments with new ones presents a severe test of the reliability of these instruments if the full scientific potential of the observatory is to be maintained. The major justification for undertaking the Space Telescope project was the promise of a rich scientific return. Thus, the prospect of a reduced science capability due to a minimal instrument replacement program seems incongruous with the overall intent, and inconsistent with the large financial investment in the original facility.

Finally, the Subcommittee was informed during the hearing that all previous planning for the ground return of the observatory for refurbishment now appears to entail an unacceptably high level of risk and cost. The Subcommittee believes that the prospect of refurbishment aboard the Space Station is a reasonable alternative providing that this operation becomes a major design consideration of the Station. Uncertainty remains, however, as to when the Station will be available for that purpose and whether the lifetime of the unrefurbished observatory can be prolonged without a grievous loss of science until the Station can accommodate such a mission.

The Subcommittee will continue to maintain an active interest in this issue inasmuch as the planning and experience will be of great value to other space-based science facilities as well.

The Subcommittee recommends that NASA, as a point of departure, explicitly present its existing plans for operations, maintenance, and refurbishment of the Space Telescope in a report to the Committee accompanying the fiscal year 1986 budget submission. The Subcommittee is particularly interested in plans for reboost and instrument replacement.

The Subcommittee further recommends that NASA request the NASA Advisory Council in consultation with the relevant boards of the National Academy of Sciences to consider how long-term observatories should be maintained and operated, with a view toward informing the maintenance and operation of other long-term space facilities.

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